INVESTIGATIONS OF THE NEUTRAL COMPOSITION OF

THE UPPER ATMOSPHERE

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SUMMARY

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A Nike-Apache rocket designated 14.62 UA was launched at 15:43 EST on March 18, 1965, from Wallops Island, Virginia. The payload consisted of a Paul massenfilter with an electron gun ion source looking out the nose of the rocket and a magnetic spectrometer which examined ambient ions looking out the side of the rocket. Also included were a magnetic and a solar aspect sensor to provide vehicle orientation data throughout the flight. The rocket reached a peak altitude of 158 km, and during its free fall time, it had a spin rate of 5.94 cps and a precession period of 37 seconds.

A power supply failure obscured the data except for a 25 second window near apogee. Both spectrometers functioned well during this period and, on the whole, reasonable agreement with previous work was achieved. Anomalously large signals were obtained at mass 14 in the neutral spectrometer and at mass 28^+ in the ion spectrometer. These anomalies are unexplained.

INTRODUCTION

This rocket experiment was performed as a prelude to the development of a neutral mass-spectrometer for use in earth satellites. The unique part of the satellite instrument, the ion source, could not be tested because its operation depends on the high velocity of the satellite. Nevertheless, it was felt that the rocket shot would prove to be a useful exercise in which several objectives might be achieved, namely:

1) Demonstrate the flight worthiness of a Paul mass-spectrometer constructed at the Southwest Center for Advanced Studies.

2) Demonstrate the flight worthiness of a magnetic mass-spectrometer constructed at the Southwest Center for Advanced Studies.

3) Demonstrate the flight worthiness of a Bendix multiplier used as a primary current detector.

4) Measure the argon-to-nitrogen concentration ratio as a function of altitude.

5) Measure the relative efficiency of a draw-in electric field for various ambient ions.

6) Provide another measurement of the E-region ion composition versus altitude.

The magnetic spectrometer was added to the experiment as an afterthought since the instrument had been almost completely developed and because the satellite ion source could be used equally well with either a magnetic or quadrupole analyzer.

INSTRUMENTS

The neutral spectrometer, including the ion source, weighed 8 lbs. and used about 8 watts average power. It had a mass range from 8 AMU to 45 AMU. The use of an oxide coated cathode was principally responsible for the lower power consumption (3 1/2 watts) of the ion source.

The magnetic ion-spectrometer weighed 5 lbs. and used 3 watts average power. The lesser physical requirements of the ion-spectrometer were due to the fact that no ion source was required for this instrument. A somewhat larger mass-range, from 11 AMU to 70 AMU, was used for the ion spectrometer. It was felt desirable to look at least as high as mass 56, since iron had previously been reported as an E-region ion.

Both instruments had mass-sweep periods of approximately 5 seconds duration, which is more than adequately short for satellite operation, but is quite marginal for rocket work. Only one instrument could be mounted looking forward, and the neutral spectrometer had to be chosen for this because of its greater over-all length. Thus the ion spectrometer results were contaminated by spin modulation, which is somewhat of a mixed blessing. While it complicates data reduction, it allows some information on the properties of the plasma wake to be gained.

FLIGHT OPERATION

Prior to launch the payload section of the rocket was maintained at a slight overpressure with clean dry air. This step was taken to

keep water from condensing anywhere in the system, so that out-gassing could occur more rapidly. The launch occurred at 15:43, well inside the ground-daylight window required. At T = +50 seconds, the nose cone and side door separated successfully. At T = +90 seconds the power to the instruments was turned on. The telemetry data indicated, after power turn on, that neither spectrometer was operating properly. Both instruments were affected in the same manner, i.e. extremely high noise level on the electrometer and mistriggering of the sweep circuit. The malfunctioning of both instruments ceased simultaneously just past apogee, and both instruments operated normally for a period of approximately 25 seconds. At this point the malfunctioning of both instruments reoccurred simultaneously and continued for the remainder of the flight.

The only item common to both instruments which could have caused the simultaneous malfunctioning was the power inverter. By careful study of the telemetry data and the circuits used in the spectrometers, it has been concluded that the regulated -12.6 volt output of the inverter was functioning improperly. The inverter was on up to the instant of launch and was operating properly. The inverter was off during the period between T = 0 and T = +90 seconds, at which time the malfunctioning was first observed.

RESULTS

Neutral Spectrometer

The power supply failure precluded the measurement of the argon-to-nitrogen ratio as a function of altitude, which was one of the

principle scientific objectives of this experiment. Data were obtained only in the altitude interval from 154.5 km to 158 km, and no appreciable difference in the peak amplitudes occurred on the 4 spectra obtained. One of these spectra is shown in Figure 1, where it can be seen that sixteen different mass peaks are present. Many of these peaks are undoubtedly due to gases associated with the rocket and not with the ambient atmosphere. The identification of which peaks are "real" and which are due to "impurities" is severely hampered by the lack of complete upleg and downleg data.

In the interpretation of the data, no correction for ram pressure effects will be included. At the time data were recorded, the velocity vector was nearly normal to the rocket axis; this fact together with the very open structure of the payload tended to prevent a pressure enhancement in the source region.

If the mass 28 peak is attributed entirely to N_2, the concentration of N_2 is found to be 1.55×10^{10} cm^{-3} at this altitude ($\sim$158 km). This agrees within 10% with the value obtained by Nier et al. at 0730 June 6, 1965, at WSMR. The good agreement is fortuitous since the overall accuracy of our measurement is probably not better than $\pm$ 50%.

The mass 14 peak is too large to be ascribed to the dissociative ionization of N_2 by the electron beam, which yields a current ratio of $[I(28)/I(14)] = 8$ according to our laboratory calibration with pure N_2. Hence we must conclude that a substantial

fraction of the 14 peak is due to an impurity [CH_2 ?] or that there
is appreciable disassociation of molecular nitrogen in the atmosphere.
The latter interpretation would lead to an N concentration of
4.65×10^9 cm^{-3}, which seems unreasonably large in view of other
atmospheric measurements (e.g. Nier et al., 1964).

The mass 16 peak yields a particle concentration of $10^{10}/cm^3$,
if the signal is considered to be due solely to atmospheric atomic
oxygen. Allowances must be made, however, for the production of O^+
from dissociative ionization of H_2O, O_2, and CO. The amount of CO
present is unknown, but the correction for the water vapor is
sufficient to account for 70% of the observed 16 peak, while the
correction for O_2 amounts to another 18%. Thus the O concentration
in the source region was only of the order of 10^9 cm^{-3}, which is a
factor of 5 less than the atmospheric concentration as measured by
Nier et al.

The O_2 concentration in the source derived from the 32 peak
is 8×10^9 cm^{-3}, compared to 1.5×10^9 cm^{-3} obtained by Nier et al.
Most of this gas undoubtedly arises from the recombination of atomic
oxygen on various parts of the structure, leading to a substantial
reduction of atomic oxygen in the instrument source. All in all,
it would appear that the total amount of oxygen, both atomic and
molecular, was perhaps somewhat larger than might have been expected,
but not by more than a factor of two.

Considering the difficulties of making measurements in this region,

the simplicity of the source design, and the lack of complete upleg

and downleg data, the results appear to be quite reasonable

except for the anomalously large value of the mass 14 peak.

Of the many other mass peaks shown in Figure 1, only OH^+

and H_2O^+ can be identified with any certainty. Reasonable choices

for the others are:

15	CH_3^+	40	$C_3H_4^+$ (A^+, MgO^+)
27	$C_2H_3^+$ (HCN^+)	41	$C_3H_5^+$
29	$C_2H_5^+$ (COH^+)	43	$C_3H_7^+$ $(C_2H_2OH^+, ALO^+, CNOH^+)$
31	CH_2OH^+	44	$C_3H_8^+$ $(CO_2^+, N_2O^+, C_2H_3OH^+)$
39	$C_3H_3^+$	45	$C_2H_4OH^+$ $(COOH^+)$

It is rather unlikely that any of the above species exist in

detectable quantities as components of the ambient atmosphere.

Some of them probably arise from the dissociative ionization of

heavier molecules; the results of this experiment, however, cannot

shed any light on this possibility.

Ion Spectrometer

The ion spectrometer functioned very well but, as in the case

of the neutral device, data were obtained only over a limited time

interval and were confined to the altitude region from 154 km to

158 km. One of the five spectra obtained is shown in Figure 1.

The noise level of the instrument is an order of magnitude worse

than preflight conditions, presumably because of inadequate shielding

of the multiplier detector from ionospheric particles which bypass

the magnetic analyzer. The entire payload section had been made as open as possible for rapid outgassing, and though charged particle traps were used to guard the detector, they were not sufficiently effective. The noise does not appear to be spin modulated as would be expected if solar radiation were responsible.

The principal ions observed had masses of 30, 32, 16, 28, and 18 AMU (assuming they were singly charged). Both the absolute ion currents and the ratios of the currents for different masses varied from spectra to spectra. The absolute currents were modulated quite strongly (a factor of the order of five) as the draw-in potential of the first grid was changed from -2 to -8 volts on alternate sweeps. The ion peaks were further modulated by vehicle spin, which caused changes of the order of a factor of five in ion current depending on whether the spectrometer opening was facing into or looking away from the vehicle velocity vector.

In spite of these rather large changes in current ratios between spectra, the average ion composition given below does not appear to be unreasonable for the three major peaks. However, the ion currents at masses other than 30, 32, and 16 are anomalously higher than the values given by Johnson et al. for daytime conditions. Some of these ions no doubt arise from reactions between ambient ions and the vehicle gases. If the 28 peak is due to N_2^+, it cannot be explained in this manner. It is also difficult to see how N_2^+ ions could escape from the source region of the neutral spectrometer,

Mass	Percent of Total Current
30	55
32	28
16	8
28	5
18	2
Others (19, 24, 26 34, & 36)	2

yet one is reluctant to accept such high ambient N_2^+ concentrations in view of the rapid reactions available for N_2^+ destruction at this altitude.

The actual ion concentrations are difficult to derive from the present data because so few spectra are available that effects of vehicle aspect cannot be sorted out. Even if more data aquisition time had been obtained, it is clear that, with a rapidly spinning (6 rps in this case) vehicle, it is essential to do one of two things: 1) sweep through the spectrum more rapidly, or 2) mount the spectrometer on front of the vehicle to eliminate the roll modulation. Choosing 1) would give somewhat reduced sensitivity, since the bandwidth of the instrument and hence the noise in the instrument would have to be increased. Also, greater telemetry bandwidth would be required (this is not usually a restriction on a rocket). On the

other hand, the height resolution of the data would also be increased. Choosing 2) would give maximum sensitivity data which are easier to analyze but it would require prime payload space which might not be available (it was not available in this flight).

CONCLUSIONS

In spite of the limited amount of useful aeronomic information gained from this flight, the shot must be considered more than just a marginal success. The following items are considered noteworthy.

a) Both spectrometers functioned well when properly supplied with power.

b) The very low power ion source (oxide cathode) which was activated in flight worked well and shows promise for satellite application.

c) The first successful mating of a flight mass-spectrometer with an ion (electron) multiplier detector was achieved.

d) It was learned that the ion current collected was a sensitive function of the draw-in electric field.

Several aspects of the instrumentation would be altered if a similar payload were to be launched again.

A much faster (by at least a factor of 10) sweep rate would be adopted for the ion-spectrometer, and better shielding for the multiplier detector would be provided. Also, with the higher sweep rate, it would be possible to have more variability in the draw-in electric field.

The neutral spectrometer would also have its sweep rate increased, but by only a factor of 2 or 3. The addition of a multiplier detector would help to increase its usefulness in looking at minor constituents. If the neutral-spectrometer were to be used to examine the neutral gas en-toto, which was not the purpose of this flight, it is essential that the device be evacuated before flight and opened up at altitude. Even ejection from the rocket should be considered, since the work of Schaeffer shows that this eliminates many of the impurities seen by Nier et al., who flew evacuated instruments but did not separate them from the rocket. Also, it would be important to extend the mass range down to 4 AMU, since the helium distribution is much more sensitive than the argon distribution in providing information about atmospheric mixing processes.

The training and experience gained from this operation will be very helpful in the design of more meaningful experiments for future flights. It is hoped that the program can be pushed forward to the ultimate goal of making useful atmospheric mass-composition measurements from a satellite.

References

1. Johnson, C. Y., Aeronomic Parameters from Mass Spectrometer, Ann. de Geophys., 17, 100-108, 1961.

2. Nier, A. O., J. H. Hoffman, C. Y. Johnson and J. C. Holmes, Neutral Composition of the Atmosphere in the 100 to 200 Kilometer Range, J. Geophys. Research, 69, 979-989, 1964.

3. Schoefer, E. J. and M. H. Nichols, Neutral Composition Obtained from a Rocket-Borne Mass Spectrometer, Space Research IV, Ed. P. Muller, pp. 265-235 (North-Holland Publishing Co., Amsterdam, 1964).

Figure 1

Ion and neutral mass-spectra taken just after apogee.
The top half of the record contains the ion-spectrometer data and
the lower half contains the neutral spectrometer data. The four
channels on the upper half are, from top to bottom,

1) Ion-current output from the electrometer.

2) Electrometer range-monitor. Each upward increment
decreases the electrometer current sensitivity by a factor
of approximately the square root of ten.

3) Voltage sweep of the magnetic analyzer. The voltage
range is from 800 volts to 120 volts.

4) Draw-in electric field monitor. The position shown
corresponds to -8 volts on the engrance grid to the spectrometer.
The five channels on the lower half of the record corresponds to,
from top to bottom,

5) Current output from the electrometer.

6) Electrometer range monitor (each step again shows a de-
crease of the square root of ten in sensitivity).

7) Monitor of the strength of the quadrupole electric
fields in the massenfilter.

8) Magnetic sensor output.

9) Optical sensor output.